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Optimizing the Number and Distribution of Heavy Tractors Needed for an 110—400 kV Electric Lines Programme

The authors aim to solve the problem of the rational utilization of the tractor stock of the enterprise which erects yearly an ensemble of 110—400 kV electric lines by : locating tractor demand and analyzing the expenses related to the transfer of some tractors from one site to another.

The erection of electric power transmission lines, which is a basic concern of the "Electromontaj" enterprise under the Electric Power Building and Assembly General Direction of the Ministry of Electric Power, is a continuous flow process, whose main operations are: the building of the poles foundations, the transportation of poles, the assembly of poles, the erection of poles, and the mounting of the active and protection conductors.

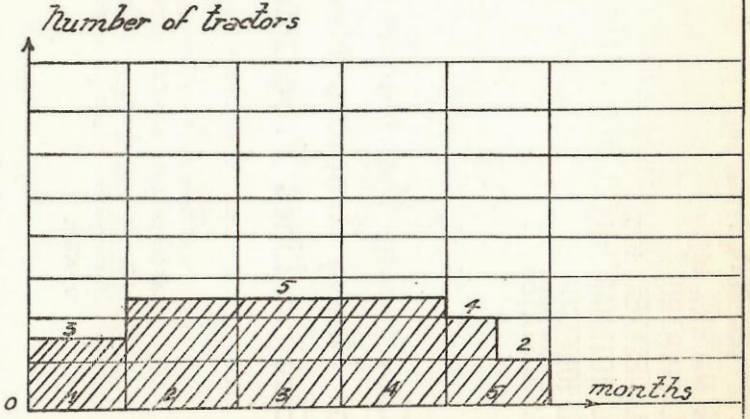
The site of an electric power transmission line stretches over tens of kilometres and consists, in fact, in a series of working zones along the direction of the electric line, nearby each pole. Under this organizational system, the mechanization of the operations for the erection of the electric power transmission lines can be achieved only with mobile mechanization means, accessible on any kind of soil. Moreover, the conveyance of the line components must also be performed with means accessible on any kind of soil. Hence the necessity to use heavy caterpillar tractors for transportation and especially for the mechanization of building operations of the electric power transmission lines.

Bearing in mind the large number of electric power transmission lines that are to be built by the "Electromontaj" enterprise in the 1967—1970 period, and the important number of heavy caterpillar tractors needed to the performing of these operations, the necessity of an optimum planning of the work for the erection of the lines appears conspicuous, so that in keeping with and strictly observing the terms set in the state plan to avoid on the one hand

Fig. 1 Diagram of the stock of tractors needed

	Name of operation	Quantity	Unit of measure	Number of tractors needed	Monthly plan — Number of tractors needed					Remarks
					1st month	2nd month	3rd month	4th month	5th month	
1	Transport of fundation materials	1200	t.	3600 t. km.	2	2				
2	Transport of line poles — concrete 200 pieces; metal 25 pieces	1200 75	t. t.	3000 t. km.	1	1	1	1		
3	Erection of line poles	225	pieces	1300 hours		2	2	2	2	
4	Erection of conductors	75 50 km.	t. km.	75 t. km. 1200 hours			2	2	2	

110 kV aerial electric lines, simple circuit, normal ground, 50-km long



peak periods in the request of heavy caterpillar tractors — by making the stock of tractors needed in the course of the year quarters as even as possible — and, on the other hand, to limit to the minimum the costs involving the moving of tractors to the sites, and from one site to other.

The study of the optimum planning of operations at electric power transmission lines in the 1967—1970 period, in keeping with the above mentioned criteria has been carried out for each year separately. The study opens, for each year, with an initial planning of these operations, the line operations with fixed terms being included in the first place, while the other line operations being distributed quite uniformly.

In order to be able to proceed to the optimization of the line operations, some preparatory work was done concerning the establishment of standard technologies of the needed tractor fleet, bearing in mind the constructive type of the line and the ground on which the line is laid (normal, uneven). To this end, standard diagrams have been drawn up of the stock of heavy tractors needed for the building of the following categories of electric power transmission lines:

— 110 kV lines, simple circuit, normal ground;
— 110 kV lines, simple circuit, uneven ground;
— 110 kV lines, double circuit, normal ground;
— 110 kV lines, double circuit, uneven ground;
— 220 kV lines, normal ground;
— 220 kV lines, uneven ground.

Fig. 1 gives as an exemple the diagram of the stock of tractors needed to the erection of the 110 kV lines, simple circuit, normal ground, which results from the totalling of the stock needed at various operations of the execution diagram.

These diagrams have three parts: the first, corresponding to the opening stage of operations; the second, corresponding to the peak period (constant stock of tractors needed, horizontal line on the diagram marking the maximum stock needed), whose length depends on the length of the line, and finally, a part corresponding to the completion stage of operations.

The diagrams have been drawn for 50 km.-long lines. For this standard line the volumes of work of the catalogue of analyses has been appreciated and the number of tractors needed for each operation has been established from the estimate norms, concerning the respective operations.

For the lines exceeding the standard length of 50 km., diagrams deriving from the standard diagrams are used, of which valid are only the first and last parts, representing the opening and closing stage of lines; a straight, horizontal line is drawn between these parts whose ordinate is equal to the ordinate of the middle part in the standard diagrams.

The drawing of the diagram of the tractor stock needed for the whole aggregate of lines, for each year in part, has proceeded on the basis of these diagrams. The graph in Fig. 2 shows the stock of tractors needed in the year 1967. To this end, the column "name of operation" includes the lines to be built in 1967. The lines were grouped in two categories: a) 220 kV lines, and b) 110 kV lines (simple and double circuit). The planning was made initially by introducing primarily the lines involving fixed schedule, and subsequently the other lines, with a quite uniform distribution.

Enterprise to carry out the operations

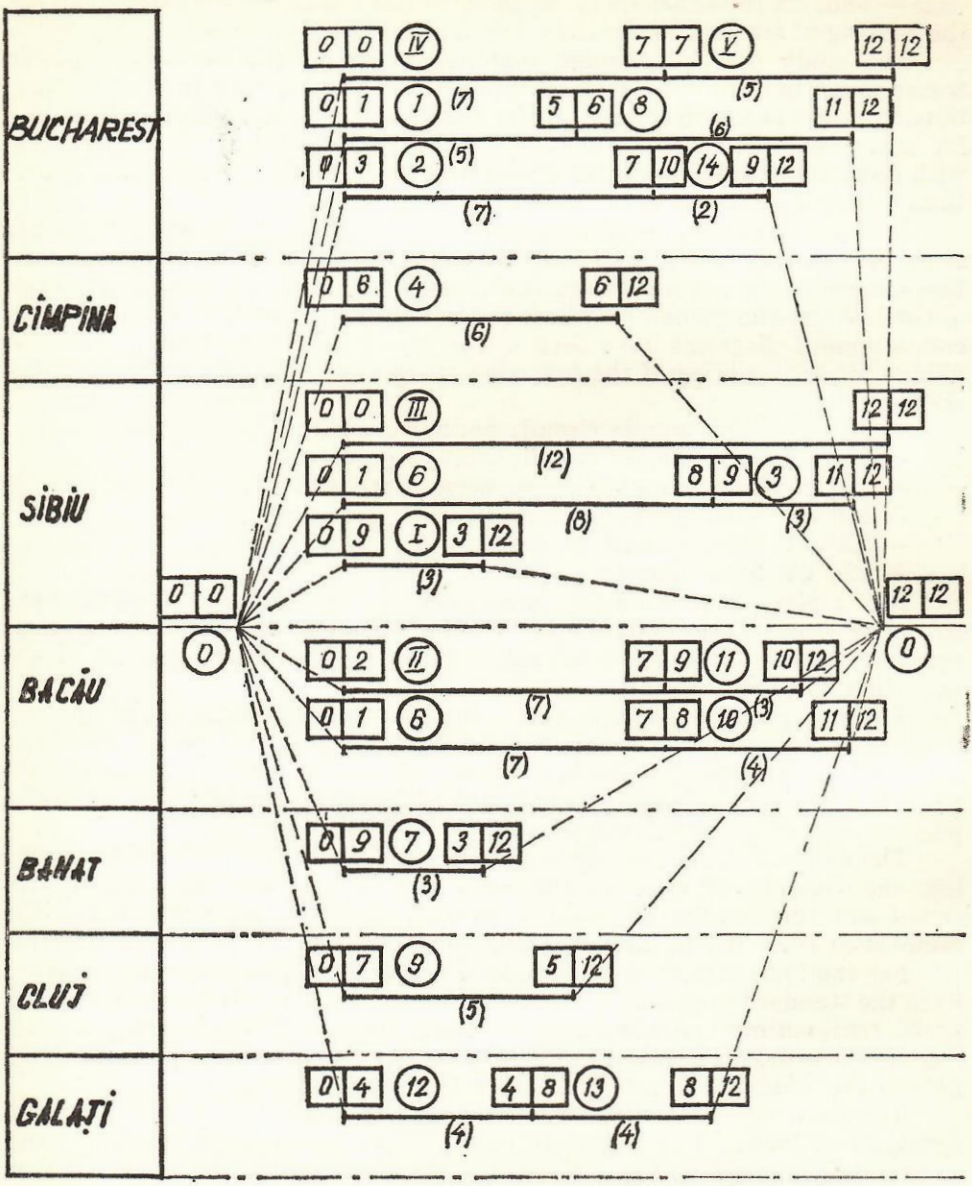


Fig. 3 (left)

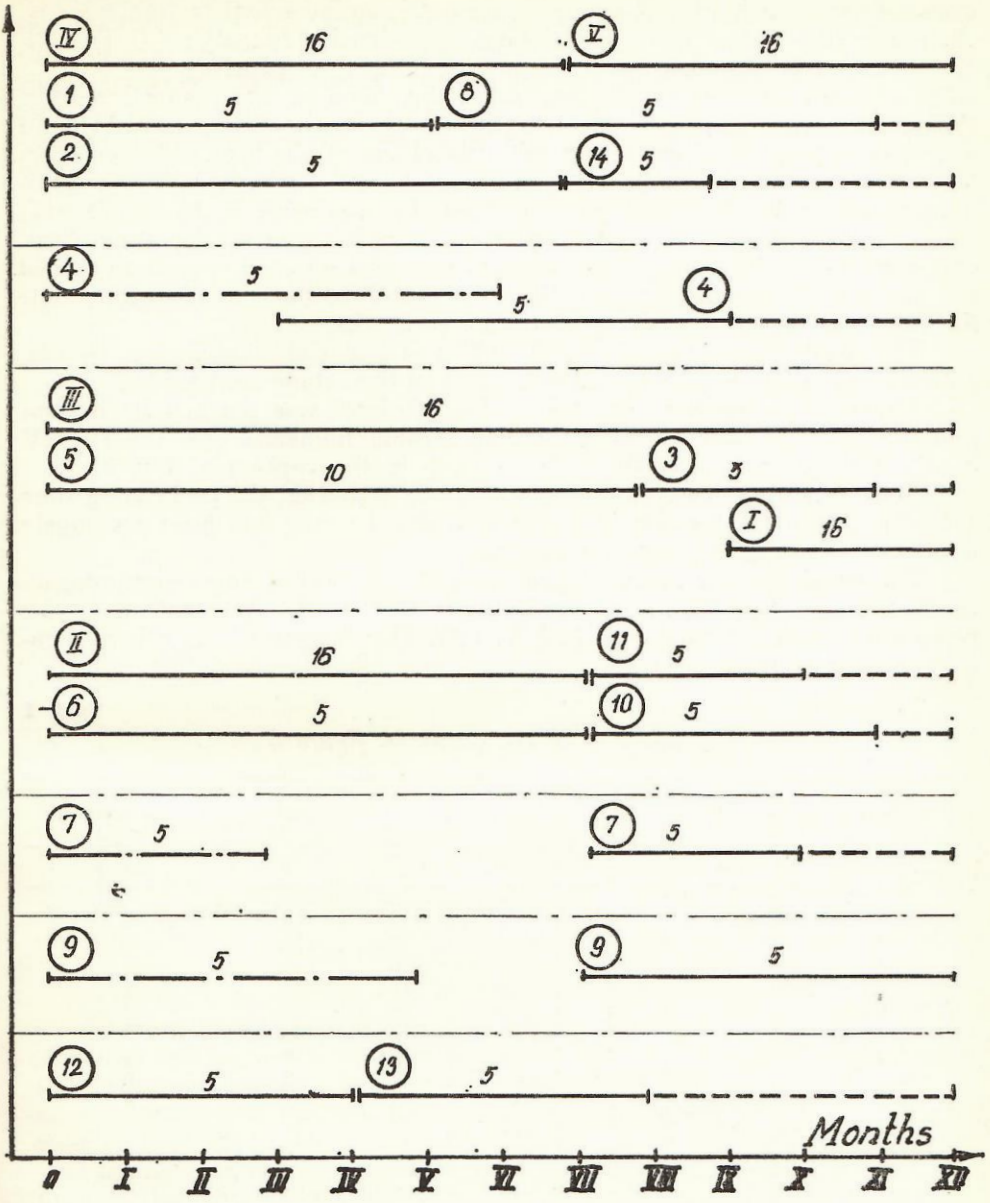

Operations
IV
16
VI
16
1
5
8
5
2
5
14
5
4
5
5
4
III
16
5
10
3
5
I
16
II
16
11
5
6
5
10
5
7
5
7
5
9
5
9
5
12
5
13
5
Months
0
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII

Fig. 3 (right)

For a more adequate planning, from the standpoint of using the resources, the graph for the aggregate of lines to be achieved in 1967 (Fig. 3) has been drawn. Bearing in mind that the lines are not interdependent technologically, the graph was centred on organizational dependencies, namely:

— the lines have been grouped per performing enterprise;

— to each enterprise were distributed the lines of the respective zone, their serial erection being planned so that the enterprise should have to build a minimum number of lines concomitantly. Thus, it has been obtained from this very stage a uniformization of the request for tractors, as well as a minimum displacement distances of the tractors (the lines being in the same zone);

— the planning of the serial erection of lines has been carried out so that, on the one hand, the total performing time of such a series of operations should not exceeed 12 months, and, on the other hand, to have as few as possible lines erected simultaneously by the same enterprise.

The graph thus obtained (Fig. 3, left) is of a special construction, that is, all the ways comprised between the initial and final stage are parallel.

Above the activities, the code of operations was marked in Roman numerals (for the 220 kV lines) and in Arabic numerals (for the 110 kV lines); the significance of the code is given in the caption of Fig. 3.

Below the direction signs representing the activities, the performing time extracted from the diagram in Fig. 2 — whose drawing had been previously explained — has been noted in brackets.

The graph has then been solved upon the method of direct computation on the scheme, and the results put down in table 1. The lines with a total 0 margin are on the critical path (IV, V, III). The margins of the other operations are given in column 7.

Table 1

Computation of the graph in figure 3

Operation	t_i^0	t_i^M	t_j^m	t_j^1	t_j^0	Total margin
1	2	3	4	5	6	7
IV	0	0	7	7	7	0
V	7	7	12	12	12	0
1	0	1	5	6	5	1
8	5	6	11	12	11	1
2	0	3	7	10	7	3
14	7	10	9	12	9	3
4	0	6	6	12	6	6
III	0	0	12	12	12	0
5	0	1	8	9	8	1
3	8	5	11	12	11	1
I	0	0	3	12	3	9
II	0	2	7	9	7	2
11	7	9	10	12	10	2
6	0	1	7	8	7	1
10	7	8	11	12	11	1
7	8	9	3	12	3	9
9	0	7	5	12	5	7
12	0	4	4	8	4	4
13	4	4	8	12	8	4

In the graphs with serialized activities, the total margin of a series of activities can be used in two ways: a) by distributing this margin on the activities in series, and b) by using this margin for the whole series, this being appreciated as one single activity. The calendar graph in Fig. 3, right, has been drawn on the basis of the data in the table. The number of tractors was written next to each line in the graph. On the basis of a sufficient approximation to the aim pursued, it was considered that the necessary stock of tractors is constant for each line and equal to the value of the necessary stock of tractors in the peak period of the erection of the line.

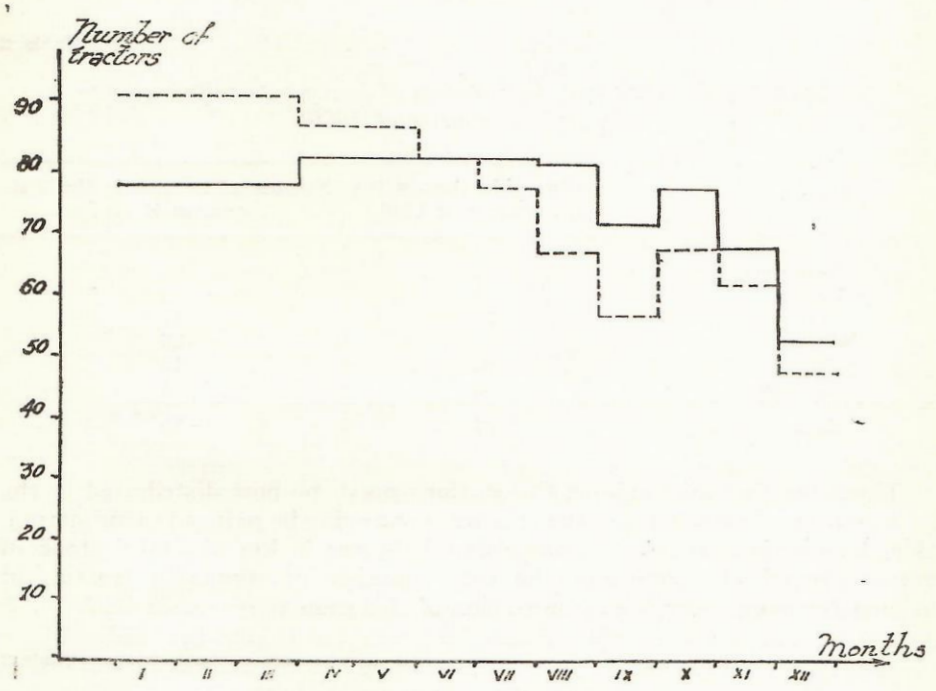


Fig. 4

The graph of the total necessary stock of tractors for the year 1967 was obtained by the graphical totalling of the tractor fleet needed (Fig. 4). Since this graph revealed a peak period in the first quarter of the year 1967, one had to proceed to the redistribution of the line operations by means of the specific RAMPS method, that is by transferring the operations from the peak zone of the diagram of the necessary stock of tractors, to the idle zones, in the limit of the margins of table 1.

For instance, the operation (7) with a 9-month margin (table 1, column 7) has been transferred horizontally to the position (7), full line. Concomitantly, the necessary stock of tractors has been displaced, and as a consequence, the graph of the total necessary stock of tractors has been changed (Fig. 4).

Thus, an acceptable graph of the necessary stock of tractors was obtained by the displacement of the lines 4, I, 7, 9, which is higher in the second and third quarters (peak quarter), and lower in the fourth quarter, when a number of tractors have to be put to capital repair.

Since the situation of the disposition on the ground of the quarters in the 4th quarter of 1966 was known at the tractor stations to which they belong, according to table 2, column 2, it can be appreciated well enough that this situation will continue in the first quarter of 1967 too, bearing in mind that 15 per cent of the fleet will be put in capital repair; hence, one can rely on $0.85 \times 96 = 80$ tractors.

Table 2

Situation of the territorial distribution of heavy caterpillar tractors in the 4th quarter of 1966

Station	Number of tractors in the 4th quarter of 1966	Number of tractors in the first quarter of 1967
Bucharest	8	7
Bacău	11	9
Ploieşti	20	17
Sibiu	31	26
Cluj	18	15
Timişoara	8	6
Total	96	80

These tractors available at the stations must be best distributed in the first quarter per operations, so that the total removing be reduced to minimum. Table 3 includes a schedule (comprising distances in km, the total stock of tractors needed at operations, the total number of available tractors at stations) for computing the optimization of this removal.

Table 3

Table of distances (km), of necessary and available stock of tractors

Tractor Station / Destination railway station	Curtea de Argeş	Bucharest	Medgidia	Hunedoara	Timişoara	Sibiu	Făgăraş	Bicaz	Vaslui	Borzeşti	Galaţi	Total number of available tractors
Bucharest	146	0	190	483	534	315	231	388	337	279	230	7
Bacău	448	302	324	629	836	461	371	86	139	93	300	9
Ploieşti	205	59	220	570	593	330	172	328	340	220	230	17
Sibiu	322	315	505	141	341	0	84	584	596	476	486	26
Cluj	520	497	687	190	250	213	297	576	629	397	732	15
Timişoara	505	534	724	190	0	301	285	922	871	813	764	6
Total of necessary stock:	16	5	5	8	8	5	5	8	5	8	5	78/80

The optimum distribution of tractors from the tractor stations to the railway stations where they are dispatched is shown in table 4.

Table 4

Tra tor Stat on	Existing number of tractors	Destination railway stations	Number of tractors distributed
Bucharest	7	Bucharest	5
		Curtea de Argeş	2
Bacău	9	Bicaz	8
		Vaslui	1
Ploieşti	17	Vaslui	4
		Borzeşti	3
		Medgidia	5
		Galaţi	5
Sibiu	26	Sibiu	5
		Făgăraş	5
		Curtea de Argeş	14
		Hunedoara	2
Cluj	15	Hunedoara	6
		Timişoara	2
		Borzeşti	5
Timişoara	6	Timişoara	6
TOTAL	80	Total of necessary stock:	78
		Available:	2
		TOTAL	80

The distribution must be corrected from the start of the other quarters (2nd, 3rd, and 4th) of the year 1967, bearing in mind the necessary stock of tractors in the diagram (Fig. 4).

For the year 1968 it has been proceeded the same as to the year 1967.

The graph of the aggregate lines of the 1968 plan was drawn, (Fig. 5, left), account being taken of the principles and methodology shown previously.

The working out of the graph stood at the basis of the calendar diagram (Fig. 5 right). The number of tractors has been marked on this diagram, upon the same procedure shown in the study of the necessary stock of tractors for the year 1967. By totalling the necessary stock, the diagram of the total necessary stock of tractors has been obtained (Fig. 6).

Since this diagram presented an important peak zone in the first quarter, then the curve decreased, the redistribution in due time of the line operations has been carried out, upon the specific RAMPS method. By transferring the lines 1, 3, 5, III, 6 of the peak zone to the idle zone, a sufficiently even diagram of the necessary stock of tractors has been obtained. According to this diagram, as many as 112 tractors are needed for the operations that will start in the first quarter of 1968.

Enterprise to carry out the operations

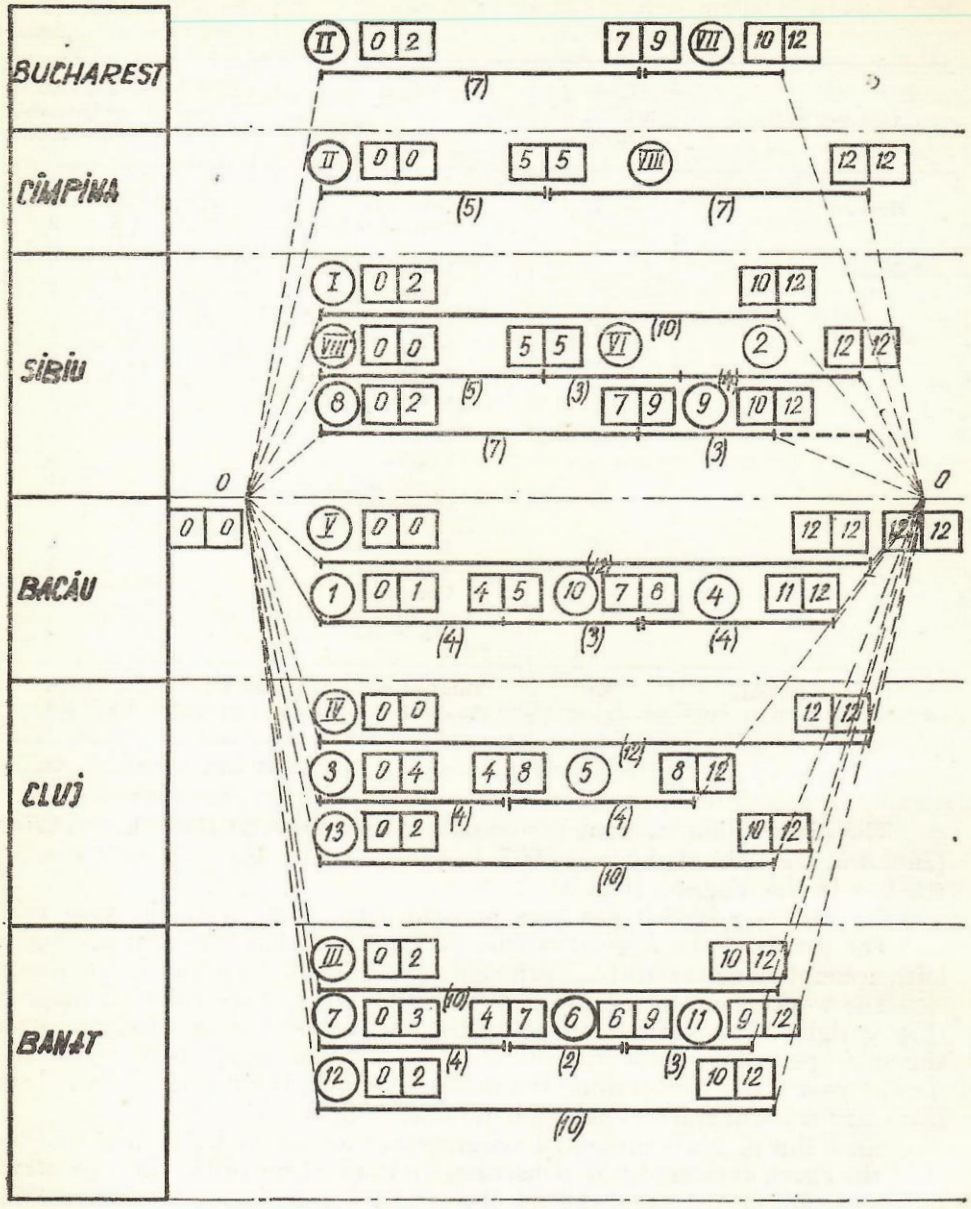


Fig. 5 (left)

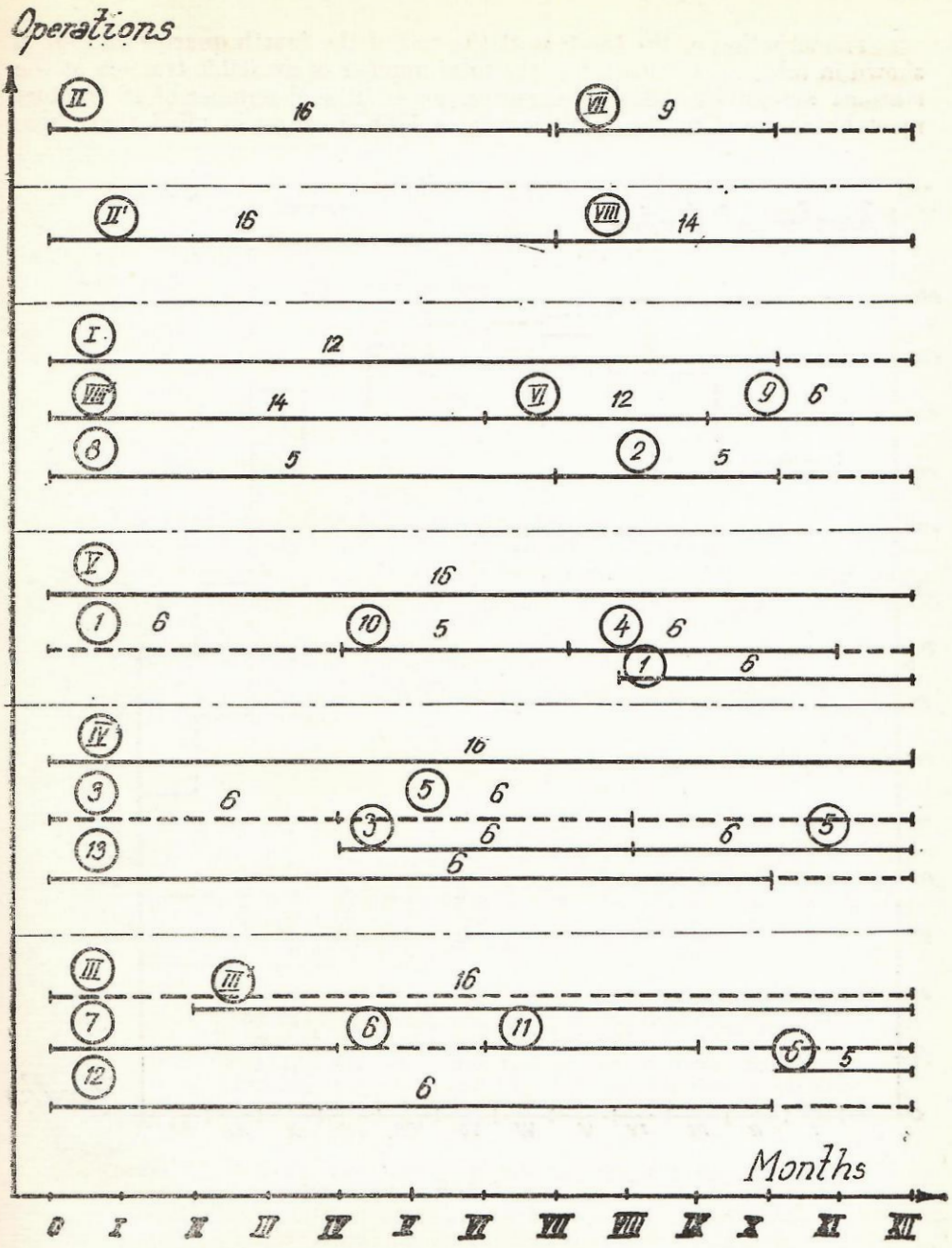

Operations
II
16
VII
9
II'
16
VIII
14
I
12
VIII'
14
VI
12
9
6
8
5
2
5
V
16
1
6
10
5
4
6
1
6
IV
16
3
6
5
6
3
6
6
5
13
6
III
III'
16
7
6
11
6
5
12
6
Months
0
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII

Fig. 5 (right)

The situation of the tractors at the end of the fourth quarter of 1967 is shown in table 5. In this table, the total number of available tractors at the stations amounts to 96. Consequently, an additional number of 16 tractors must be acquired in the first quarter of 1968. Bearing in mind that these

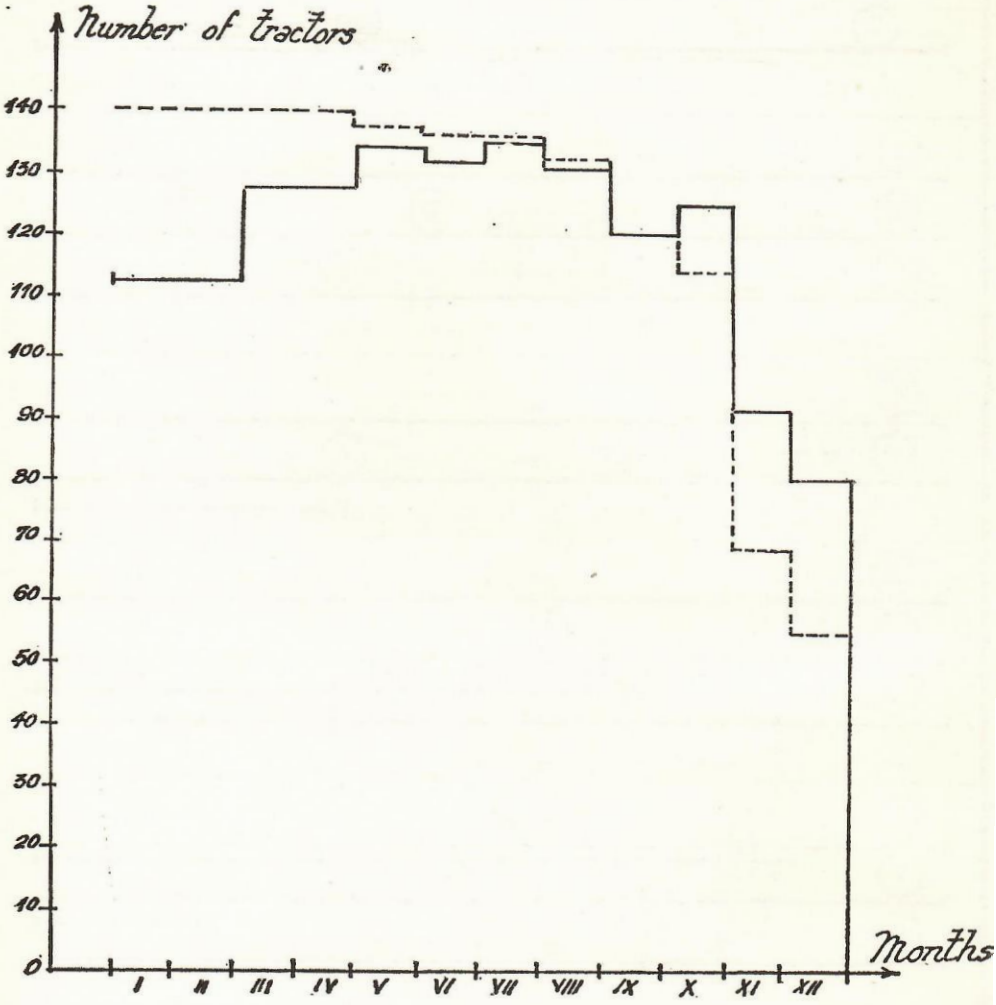


Fig. 6

tractors are to be obtained either by purchasing new tractors from Brașov (10 pieces) or hiring 6 pieces from Craiova, table 6 has been drawn with the distances in km., the total necessary stock of tractors for operations and the available number of tractors in stations.

Table 5

Situation of the tractors existing at the end of the 4th quarter, 1967

Operations	Number of tractors	From the station	Tractors existing at stations	Total number of tractors available at stations
Bucharest	26	Bucharest	—	26
Sibiu	37	Sibiu	—	37
Bacău	10	Bacău	—	10
T.m șoara	5	Timișoara	—	5
Cluj	5	Cluj	6	11
		Ploiești	7	7
Total	83		13	96

The extra necessary stock of tractors may be acquired throughout the first quarter of 1968, since in the approximation made at the totalling of the necessary stock the gradual putting into operation of the tractors has not been taken into account. This fact justifies, as a matter of fact, the accepted approximation.

The tractors needed to supplement the existing stock of 112 to 134 pieces (the necessary stock in the diagram of Fig. 6) must be purchased from the start of the 2nd quarter.

Table 6

Destination station / Tractor station	Bucharest	Brașov	Cîmpina	Turnu Măgurele	Craiova	Borzești	Galați	Baia Mare	Tîrgu Mureș	Miercurea Ciuc	Lugoj	Reșița	Total number of available tractors
Bucharest	0	166	92	150	209	279	230	626	448	261	475	478	26
Bacău	302	312	386	452	511	93	300	566	388	342	777	780	10
Ploiești	59	107	33	209	268	220	230	567	389	202	534	537	7
Sibiu	315	149	223	389	230	476	486	385	189	244	248	282	37
Cluj	497	331	405	587	428	397	732	194	246	289	291	325	11
Timișoara	534	490	564	484	325	813	764	371	341	474	59	142	5
From other sources:													
Craiova	209	375	299	159	0	488	439	582	403	590	266	269	6
Brașov	166	0	74	316	375	327	337	460	282	95	391	425	10
Total necessary stock	16	22	8	6	11	8	8	8	8	6	5	6	112

Optimum repartition of tractors in the 1st quarter of 1968 is shown in table 7.

Table 7

Tractor station	Existing number of tractors	Destination station	Number of tractors distributed
Bucharest	26	Bucharest	16
		Turnu Măgurele	6
		Galaţi	4
Bacău	10	Borzeşti	8
		Galaţi	2
Ploieşti	7	Cîmpina	3
		Galaţi	2
Sibiu	37	Braşov	12
		Cîmpina	3
		Craiova	5
		Tîrgu Mureş	8
		Miercurea Ciuc	6
		Reşiţa	3
Cluj	11	Baia Mare	8
		Reşiţa	3
Timişoara	5	Lugoj	5
From other sources:			
Craiova	6	Craiova	6
Braşov	10	Braşov	10
Total:	112	Total:	112

CONCLUSIONS

1. The planning of the erection of overhead electric lines in the plan of the "Electromontaj" enterprise has proceeded bearing in mind an as constant as possible necessary stock of heavy tractors in the course of the quarters of the year. Thus, the plan of necessary stock of heavy tractors is constant, slowly decreasing in the 4th quarter. This is an optimum planning for the enterprise using the equipments, since it had no "peak periods" and enables the putting in capital repair of the tractors during the 4th quarter of the year, when work on site is less intensive.

2. The proposed planning of the erection of lines, in compliance with the result of the optimization of the necessary stock of tractors corresponds at the same time from the point of view of their execution, since:

— the lines were grouped per performing enterprise in an approximately equal proportion, which ensures an intensive carrying out of operation;

— the serial erection of the lines was planned in each enterprise, each operation succeeding one another, big savings being achieved at the organization of sites;

— only 1—2 such systems of operations were planned in each enterprise in order to avoid peak periods and make the necessary material means uniform.

3. The proposed planning of the line erection optimizes not only the demands for tractors, but also the demands for other material resources and labour force.

4. The distribution of the tractors from the tractor stations to the sites early each year has been optimized by the method of linear programming; the optimum distributions in the year 1967 are shown in table 4, and in the year 1968, in table 7.

5. Savings resulting from:

— avoiding the purchase of 6 tractors in 1969 — 360,000 lei

— avoiding the payment of redemption due for the tractors unused in 1968 — 199,800 lei

$28 \times 2 \times 3.7 = 207{,}200$ lei

in the 1st quarter $12 \times 1 \times 3.7 = 44{,}400$ lei

in the 4th quarter $10 \times 1 \times 3.7 = 37{,}000$ lei

$22 \times 2 \times 3.7 = 162{,}800$ lei

199,800 lei

Since the equipment can be kept unused one quarter per year, it results that the redemptions in the first quarter would not be borne, while the redemptions of the 4th quarter should be borne by the enterprise. Payments worth 199,800 lei are thus being avoided.

— More economical conveyance of the tractors; some 1,000 wagon/km × 800 lei/100 km — 8,000 lei

Total: 567,800 lei

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OPTIMISATION DU NOMBRE ET DE LA DISTRIBUTION DES TRACTEURS LOURDS REQUIS POUR UN PROGRAMME DE MONTAGE DE LIGNES ELECTRIQUES DE 110–400 kV

Dans le cadre d'une grande entreprise qui monte des lignes électriques de haute tension on utilise un nombre important de tracteurs lourds (sur pneus ou sur chenilles) pour les opérations d'assemblage et d'érection des poteaux et pour emplacer les conducteurs électriques. L'utilisation rationnelle de ces tracteurs entraîne d'importantes économies.

On établit, techniquement, la quantité de tracteurs nécessaire pour différentes catégories de lignes électriques (tension : 110, 220 et 400 kV ; terrain : accidenté et normal ; structure de la ligne : circuit simple et circuit double).

On établit un plan initial en fonction de certains délais de livraison obligatoires. On calcule pratiquement la quantité de tracteurs nécessaires pour différentes périodes, obtenant ainsi le graphique de la quantité de tracteurs nécessaire qui, d'habitude, comporte des sommets et des dépressions.

On procède ensuite à l'établissement du graphique des programmes d'exécution de l'ensemble des lignes en tenant compte des principes suivants :

— on groupe les lignes par région ;

— on totalise, dans le cadre d'une meme région, l'exécution des lignes dont la période totale de montage n'excède pas 12 mois.

On résoud le graphique, on construit le graphique ayanit trait à la quantité de tracteurs nécessaire, on l'applatit à l'aide des méthodes RAMPS spécifques par la translation des lignes dans le cadre des marges libres.

On calcule, à la fin de chaque trimestre, par la méthode «stepping-stone», le déplacement des tracteurs, obtenant ainsi des frais de transport minimums.

L'applatissement de la quantité de tracteurs nécessaire évite l'achat de tracteurs aux périodes de pointe, ainsi que la charge d'amortissements des tracteurs non-utilisés aux périodes de vide. La distribution des tracteurs par la méthode «stepping-stone» a comme conséquence des frais de transport minimums.

La planification rationelle des lignes mène également à une utilisation rationenlle d'autres ressouces matérielles.

ОПТИМИЗАЦИЯ ПАРКА И РАСПРЕДЕЛЕНИЯ ТЯЖЕЛЫХ ТРАКТОРОВ ПРОГРАММЫ ВВИДУ СТРОИТЕЛЬСТВА ЛИНИЙ ЭЛЕКТРОПЕРЕДАЧИ С НАПРЯЖЕНИЕМ 110—400 кВ

Крупные предприятия, строящие высоковольтные линии электропередачи, используют большое число тяжелых (колесных и гусеничных) тракторов для операций по сборке и установке опор и натяжке электропроводов. В результате рационального использования этих тракторов осуществляется значительная экономия.

На основании технологических данных определяется необходимое количество тракторов для различных категорий линий электропередачи (напряжение: 110, 220 и 400 кв; местность: пересеченная или нормальная; структура линии: простая или двойная сеть).

Производится инициальное планирование в зависимости от некоторых обязательных сроков. Составляется график, основанный на вычислении необходимого количества тракторов по различным периодам; полученный таким образом график необходимого количества тракторов обычно содержит и периоды их максимального и минимального использования (простоя).

Затем приступают к составлению графика программ выполнения строительства всех линий в совокупности с учетом нижеследующих принципов:

— линии группируются по областям;

— для каждой области суммируются все работы по строительству линий, общая продолжительность которых не превышает 12-ти месяцев.

Решается граф, составляется график необходимого числа тракторов, который выражается затем по специфическому методу RAMPS, путем перемещения линий в границах свободных мощностей.

Перевод тракторов на новое место работы в конце каждого квартала вычисляется методом «stepping—stone», при помощи которого определяются минимальные расходы по их перевозке.

Выравнивание графа необходимого числа тракторов позволяет избегнуть покупку тракторов в периоде их максимальной необходимости и выплату амортизаций тракторов, использованных в периоды простоя. Распределение тракторов по методу «steppieg—stone» ведет к сокращению до минимума расходов по их перевозке.

Рациональное планирование строительства линий ведет к рациональному использованию и других материальных ресурсов.

STOCK OF TRACTORS NEEDED IN 1967

	NAME OF OPERATION	QUARTER I	QUARTER II	QUARTER III	QUARTER IV
	AERIAL ELECTRIC LINES 220 kV				
I	CRAIOVA - TR. MĂGURELE				4 7 12
II	BICAZ - BORZEȘTI		16	11 5	
III	HUNEDOARA - TIMIȘOARA		16		11 5
IV	AREFU - RM. VÎLCEA	4 7	15 16	11 5	
V	AREFU - PITEȘTI			4 9	15 16 11 5
	AERIAL ELECTRIC LINES 110 kV				
1	BUCHAREST - TĂMĂDĂU	3	5	4 2	
2	MEDGIDIA - BANEASA	3	5	4 2	
3	PAROȘENI - PETRILA	4 6	5 2		
4	BRAȘOV - TG. SECUIESC	3	5	4 2	
5	SIBIU - FĂGĂRAȘ D.C.	4	10	4 2	
6	VASLUI - IAȘI	3	5	4 2	
7	CÂRPINIȘ - LOVRIN			3	5 4 2
8	TĂMĂDĂU - DOROBANȚU			3 5	4 2
9	DEJ - BISTRIȚA	3	5	4 2	
10	FRASIN - G. LUNG.			4 6	5 2
11	BORZEȘTI - MOINEȘTI				4 6 5 2
12	GALAȚI - FOLTEȘTI			3 5	4 2
13	MĂCIN - TULCEA				3 5 4 2
14	PALAS - MAMAIA			5	